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CROPS RESEARCH

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CRAMBE

A Potential New Crop for Industrial and Feed Uses

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

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CRAMBE

A Potential New Crop for Industrial and Feed Uses

The Agricultural Research Service of the United States Department of Agriculture, in cooperation with State agricultural experiment stations, has research under way to discover and develop new crops for the American farmer. Two major purposes will be achieved in direct proportion to the success of this research program: (1) Agricultural diversification will be broadened as the farmer is provided with additional alternative crops; (2) new raw materials will become available to industry from stable domestic sources. The search for new crops is concentrated on potential sources of industrially useful chemical constituents not found in usable quantities in our present crop plants; and constituents with superior quality or lower production cost, or both. Unique seed oils, gums, nutritionally superior proteins, and stalk fibers for paper pulp are objectives of a broad screening program for new crops. Plant scientists and utilization scientists have teamed up to promote this search. Crop evaluations and utilization evaluations of each new crop prospect are jointly and carefully considered at each stage in the process of bringing wild plant species to successful crop status. One of the most promising potential new crops is Crambe, which is currently being investigated as a source of erucic acid in the seed oil.

BOTANICAL DESCRIPTION

Crambe abyssinica Hochst. ex R. E. Fries (Family: Cruciferae) is the only annual member of a genus of some 20 species of mostly perennial herbs and sub-shrubs. The genus is distributed from the Mediterranean to central Asia and western Europe. Two species are cultivated to some extent. One, *C. maritima* L., is grown in vegetable gardens for its succulent spring shoots; the other, *C. cordifolia* Steven., is grown as an ornamental.

C. abyssinica is an erect herb up to about 3 feet tall that branches mostly in the upper half of the plant. The leaves are large and pinnately lobed. The inflorescence is of long panicled racemes, the lateral branches of which are sharply ascending and shorter than the primary axis. Flowering is indeterminate; the numerous spherical pods are one-seeded and indehiscent. In spite of the indeterminate flowering habit, the first-formed pods usually remain on the stalk until the last-formed pods mature.

The ARS research on Crambe discussed in this report is based on a limited sampling of the genus as a whole and within *C. abyssinica*. It suggests that even more promising genetic stock may be found when *C. abyssinica* and other species are more adequately sampled.

CHEMICAL COMPOSITION

The gross chemical composition of *C. abyssinica* seed is similar to that of other members of the mustard family. The seed is rich in oil and protein. Erucic acid is the major fatty-acid component of the seed-oil. Thioglucosides that may affect nutritional value or palatibility are contained in the high-protein meal. These glucosides are readily hydrolyzed by the types of enzymes present in mustard seed.

Seed

C. abyssinica seed from nine locations in the United States were analyzed in U.S. Department of Agriculture laboratories for oil and protein content and proportion of hulls. Typical analyses (dry basis) for good-quality seed are 45.7 percent oil and 26.8 percent protein in hull-free seed; 39.7 percent oil and 24.7 percent protein in seed analyzed as harvested (containing 23.6 percent hulls): weight per thousand seed 6.4 g. with hulls, 4.4 g. hull-free. Seed, with hulls, varied in oil content from 25 to 40 percent and varied in protein content from 20 to 29 percent. These values are within the ranges reported by most European investigators; however, oil percentages greater than 50 percent were claimed in some instances.

The proportion of hulls is a preliminary guide to sample quality. Some samples, grown or harvested under other than optimum conditions, contained an abnormally large proportion of hulls due in part to pods either unfilled or containing incompletely developed seed.

The interior of *C. abyssinica* seed is yellow. One sample of dehulled seed contained 18 p.p.m. of xanthophyll and 1 p.p.m. of carotene. Yellow corn contains, on the average, about 25 p.p.m. of xanthophyll and a little over 2 p.p.m. of carotene.

Oil

Typical composition of *C. abyssinica* seed oil, as determined in Department laboratories, is:

Acid	Percent	Acid	Percent
Erucic	59	Other C_{22} acids	2
Oleic	18	Other C_{18} acids	1
Linoleic	10	C_{20} acids	3
Linolenic	5	C_{16} acids	2

Erucic acid content ranged from 54 to 61 percent.

USDA laboratories have analyzed 129 seed samples representing 90 species and 38 genera of Cruciferae. Of these, *C. abyssinica* oil contained the highest percentage of erucic acid. Domestic oilseeds are not utilized for the production of erucic acid. Crambe oil, therefore, is unlikely to compete directly with domestic oils in industrial applications.

The molecular structure of *C. abyssinica* oil is unusual. The erucic acid in the oil is attached at very specific positions to the glycerol which makes up the other part of the molecule in a vegetable oil. This selectivity is in contrast to the random or other statistically probable types of arrangement found in many other oils. This structural information was developed in an industrial laboratory. Oil for the investigations was supplied from seed experimentally produced under USDA sponsorship. Such information on the fundamental chemical structure of crambe oil may be important in determining useful characteristics and guiding further utilization studies.

Hexane-extracted Seed Meal

Hexane-extracted meal from a typical sample of *C. abyssinica* seed (with hulls) contained 41 percent of crude protein (Kjeldahl nitrogen x 6.25). A similar meal from dehulled seed contained 49.4 percent of crude protein and about 6.5 percent of ash. Amino-acid composition of the meal is--

Amino acid	g./16g. meal nitrogen	Amino acid	g./16g. meal nitrogen
Lysine	5.0	Histidine	2.4
Methionine	1.6	Arginine	5.9
Cystine	2.7	Glycine	5.0
Isoleucine	3.8	Alanine	4.0
Leucine	6.2	Aspartic acid	7.2
Phenylalanine	3.7	Glutamic acid	16.4
Tyrosine	2.6	Hydroxyproline	0.6
Threonine	4.4	Proline	5.8
Tryptophan	1.0	Serine	3.8
Valine	4.8		

The amino-acid analysis of *C. abyssinica* seed meal resembles that of species of other genera of the mustard family. The meal has a favorably high content of lysine and of the sulfur-containing amino acids, which are common nutritionally limiting factors in vegetable-seed proteins.

The high protein content and nutritionally favorable amino-acid composition of *C. abyssinica* meal should encourage its use in the preparation of supplements for feeding with corn and other grains. However, caution must be exercised in interpreting the chemical analyses until feeding trials are completed. A seed meal can serve as a satisfactory supplement only when the amino acids are biologically available and antinutritional or toxic factors are absent or readily removed or inactivated during processing. Palatability of the meal and preservation of its quality during processing are other important factors.

Oilseed meals commonly require special processing to attain maximum nutritional quality. This will be true of Cruciferae, since they contain complex sulfur compounds in their seed and foliage. Some of these compounds are acted upon by enzymes to yield glucose and inorganic sulfates and a variety of pungent volatile mustard-oils like those in table mustard. Other mustards contain more complex nitrogen- and sulfur-bearing compounds, of which only a few are fully identified and some are toxic.

Untreated oil-free C. abyssinica seed meal is toxic to rats. The meal contains at least six sulfur-bearing compounds, other than sulfur-containing amino acids, that are similar to the toxic and/or unpalatable substances, present in other crucifers. Much basic research is required to identify these compounds and to assess their significance in the use of Crambe meal for feed. This research is now in progress and will be useful in guiding processing for the removal of undesirable minor components or their conversion to innocuous form.

Seed Processing

USDA chemical engineers recently developed a process for efficiently recovering oil and bland meal from yellow oriental-mustard seed, Brassica juncea (L.) Coss. The process involves release of volatile mustard oil by enzymatic hydrolysis of flaked moistened seed. This essential oil is recovered by steam distillation. The fixed or glyceride oil remaining in the meal is separated by filtration and extraction. Knowledge gained from this research is being applied to studies of the processing of C. abyssinica seed.

USE OF RELATED OILSEEDS

Rapeseed and mustardseed oils contain erucic acid, but in a smaller proportion than C. abyssinica.

Rapeseed is one of the principal oilseeds of the world. Production was at an all time high in 1961. More than 4 million tons was produced--almost 3 million tons in Asia, especially India; half a million tons in eastern Europe, including the U.S.S.R.; 400 thousand tons in western Europe; 52 thousand tons in South America; and a little less than 300 thousand tons in North America, largely in Canada. Canadian rapeseed production has been high since 1956 (average production 1950-54, 7.8 thousand tons).

Almost all rapeseed is processed for edible oil. The extracted cake can serve as animal feed, but with restrictions because of undesirable chemical components. The scientific literature advises caution in the amount of meal incorporated in feeds, especially for swine and poultry. In Canada, the percentage of rapeseed meal in animal rations is limited by regulation.

Rapeseed oil is used by industry as a raw material for preparing rubber additives. During World War II it was employed for compounding marine-engine lubricants. Current importation of rapeseed and rapeseed oil into the United States is about 3 million pounds per year.

Mustardseed is grown in the United States only as a condiment. It is produced primarily in Montana and California. These two States produced about 16 million pounds in 1959. In the same year 24 million pounds were imported.

Work on the yield potential of mustard in the midwestern United States and its marketing possibilities as a processed oilseed has shown that large-scale commercialization will depend upon new end uses for the oil. As a crop source of an oil high in erucic acid, it is appropriate that research on new end uses center on C. abyssinica.

UTILIZATION PROSPECTS

The best markets envisioned for products derived from C. abyssinica seed are those based on industrial utilization of the oil or of substances prepared from the oil. Realization of the full potential will require more intensified research. A number of end uses into which erucic acid oils or derived chemicals may be channeled are discussed below. Some of these are subjects of U.S. Department of Agriculture research programs.

Uses Based on Erucic Acid Cleavage Products

The mixture of fatty acids obtained when Crambe oil is hydrolyzed will in practice be fractionated to yield purified erucic acid or a fraction rich in that component. Splitting of unsaturated fatty acids by ozonolysis is a well-known industrial procedure. Some research will be required to adapt this procedure to the production of erucic acid from Crambe oil.

Two products are derived from oxidative splitting of erucic acid--the 13-carbon dibasic brassylic acid and the 9-carbon monobasic pelargonic acid. Brassylic acid is generally unavailable, although a small amount may be manufactured for use in the preparation of perfume-chemical intermediates. Related dicarboxylic acids, such as 9-carbon azelaic acid and 10-carbon sebacic acid, are commercially available. In 1959, 8 million pounds of azelates and 10 million pounds of sebacates were used as plasticizers. Availability of brassylic acid would expand the range of the properties attainable with this important class of compounds and possibly lead to their expanded use.

There is a potential market for high-purity brassylic acid for the production of new polyamide fibers. Potential markets for grades of lesser purity are in the production of materials such as plasticizers, polyesters, alkyd resins, lubricants, and surface-active agents. These end uses could create a demand for about 15 million pounds of brassylic acid per year. Additional processes now under investigation may create other markets for dibasic acids. A new process for applying a shrink-resistant finish to woolen textiles is a good example.

Pelargonic acid is used for the production of jet-engine lubricants, plasticizers, alkyd resins, vinyl stabilizers, flotation agents, and insect repellents. Disposal of the additional supply of pelargonic acid created as a co-product of brassylic-acid production may require development and applications research and promotion to assure new markets.

Current research objectives of Department laboratories include the development of optimum procedures for high-yield production, separation and purification of brassylic acid, and the preparation of a variety of brassylic-acid derivatives for use in plasticizers and other products.

Uses Based on the Whole Oil

Erucic acid containing oils are used in the Unied States primarily for the preparation of rubber additives. All of this oil, about 2-1/2 million pounds per year, is imported.

Erucic acid containing oil has traditionally been used as a lubricant or a component of lubricants manufactured from petroleum. Although such oils have very favorable lubricating properties; current usage for this purpose is very small. Aggressive research on applications of erucic acid oil or its derivatives in the lubricant field could be rewarding.

Completely hydrogenated Crambe glyceride oil is a white solid with excellent hardness. It is of potential value as a component of wax compositions.

Uses Based on Erucic Acid or Its Derivatives

Amides and other nitrogenous derivatives of fatty acids are used for imparting water repellency to textiles. Generally, increasing the percentage of carbon in an organic compound increases its hydrophobic character. Since derivatives of erucic acid contain a high percentage of carbon, they will probably have superior water-repellent properties. Recent industrial research in this field provided products with good water repellency. These products are useful for treating textiles and are of possible value as insolubilized paper coatings. This research was based on behenic acid, a product derived from erucic acid by hydrogenation.

Waxlike products have been prepared from Crambe oil acids esterified with the fatty alcohols derived from Crambe oil by reduction. The original liquid esters are readily converted by reaction with hydrogen to white waxy solids. These waxy solids are softer than the hydrogenated Crambe glyceride oil, but have higher melting points and a more "crystalline" appearance. These waxes merit further evaluation to ascertain whether this combination of properties may have industrial utility.

AGRONOMIC RESEARCH IN OTHER COUNTRIES

Russia

C. abyssinica has been grown experimentally in the U.S.S.R. since 1932 as a potential source of oil. Test plantings were studied at several hundred locations over wide geographical and ecological ranges. Most plantings yielded from 1,000 to 1,300 pounds of seed per acre. Seed (with hulls) contained from 25 to 33 percent of oil. The oil content of dehulled seed ranged up to 54 percent.

Comparisons of 29 "species" of Crambe assembled in Russia from that and adjacent countries indicated that C. abyssinica has the greatest crop potential.

Tests under a wide range of conditions suggested that C. abyssinica is not exacting in its cultural requirements and will withstand temperatures down to 23° F. The most favorable response was in the Leningrad district when C. abyssinica was sown early in May in rows about 12 inches apart at the rate of 18 to 22 pounds of seed per acre. In the Dniepropetrovsk district a planting seeded in the first half of April yielded 1,874 pounds of seed per acre with an oil content of 35 percent. The best depth of seeding was from 1.2 to 1.6 inches.

Sweden

Crambe was planted at the Weibullsholm Plant Breeding Institute at Landskrona, Sweden. These experimental plantings yielded about 1,800 pounds of seed per acre even though the pods tended to shatter. The seed contained 52 percent of oil "of the rapeseed type." The solvent-extracted meal contained 44.8 percent of protein.

EXPERIMENTAL PLANTINGS OF CRAMBE ABYSSINICA IN THE UNITED STATES

Maryland

Response to environmental conditions, particularly temperature, was studied at the U.S. Plant Introduction Station at Glenn Dale. The best development occurred at relatively cool temperatures comparable with the moderate winters of southern areas and the relatively cool summers of the Northern States.

Nebraska

Plantings were made at Lincoln on May 1, 1 inch apart, with 12 inches between rows. The plots were fertilized before seeding with 40 pounds of nitrogen and 40 pounds of P_2O_5 per acre. The yield was 1,616 pounds of seed (including hulls) per acre. Precipitation from March to October, inclusive, was 21 inches considerably above average. Yields of weed-free and uncultivated plots did not differ appreciably.

Wyoming

Plantings were made at Cheyenne on May 29, 6 inches apart, with 30 or 42 inches between rows. The seed germinated readily; the plants began flowering on the 60th day; and the crop was harvested on September 25. Many seeds were green at harvest, suggesting that mowing and windrowing prior to combining may be necessary. Plots seeded in 30-inch rows yielded 2,243 pounds of seed per acre; those seeded in 42-inch rows yielded 1,976 pounds of seed per acre.

Texas

Plantings were made at Weslaco on December 20, and combined on April 14. Plots yielded an average of 861 pounds of seed per acre. In 1961 a similar planting at the seedling stage was destroyed by an unusually low January temperature of 12° F.

Iowa

Replicated plots seeded at Ames on April 22 were fertilized with the equivalent of 10, 30, and 50 pounds of nitrogen per acre and 20, 40, and 60 pounds of K_2O per acre in all possible combinations. The yields of these plots in pounds per acre were (average of four replications):

Nitrogen per acre pounds	K_2O per acre			
	20 pounds	40 pounds	60 pounds	Average
10	1,069	1,007	1,096	1,057
30	1,178	1,032	1,012	1,074
50	1,279	1,393	1,208	1,293
Average	1,175	1,144	1,105	--

Analysis of variance indicated a significant effect at the 5 percent level for nitrogen but no significant effect for potassium.

Montana

Plantings were made at Bozeman on June 1 on land relatively low in nitrogen and harvested on October 1. Seed yields (including hulls) ranged from 1,300 to 1,900 pounds per acre. The lower leaves tolerated frosts and remained green until harvest. Other cruciferous crops in this area were severely damaged by flea beetles. The *C. abyssinica* plots were virtually undamaged by these and other pests.

RESEARCH OBJECTIVES AND PROBLEMS

Chemical Research

Some uses of erucic acid oils detailed in this special report now exist in industry. Others are more speculative but are soundly based on chemical knowledge and analogies with utilization of related materials. Fertile fields of investigation relative to the chemistry, processing, and utilization of erucic acid oils and products derived from them remain to be fully explored. Research likely to produce fruitful results includes: study of the dimerization of erucic acid and properties and uses of the dimer acid; preparation of surfactants from erucic acid derivatives; preparation of chemical derivatives by reactions already accomplished with oleic acid, and study of the characteristics and applications of such derivatives; production of lubricating compositions from erucic acid oils; application of new chemical reactions to erucic and brassylic acids for the preparation of potential commercial products; and further study of the processing of erucic acid containing seed to achieve efficient recovery of oil and acceptable feed meal.

Agronomic Research

Current research is designed to establish the environmental and cultural requirements of *C. abyssinica* in a variety of locations in the United States. An entire array of production details, from planting through harvest, must be studied. These investigations will provide a basis for preliminary cultural recommendations and the design of research leading to crop improvement. The following factors are being studied in field and greenhouse experiments:

Plant habit, as influenced by environment and culture;
Temperature factors, including the extremes tolerated and the range conducive to optimum development;
Soil, the influence of soil types on growth and productivity;
Water requirements, correlation of plant growth and yield with rainfall or irrigation;
Planting and harvesting dates, as influenced by day length and other environmental factors;
Planting depth and density, relative to local environment;
Fertilization, the influence of specific nutrients on yield and quality of seed under both irrigated and dry-land conditions;
Seed maturation, in relation to harvesting efficiency (harvesting by combine will be essential to the development of economical production methods);
Handling and storage of seed, as influenced by stage of maturity and other quality characteristics; and
Crop improvement, identification of plant characteristics of potential value in selection and breeding.

Pest control measures will be developed when necessary. Crambe has been outstandingly free of diseases and insects in experimental plantings.

Experimental plantings will be established at 24 locations in 14 States during 1962. Encouraging data from previous plantings indicate that it may be possible to bring Crambe to crop status within a few years. The 1962 investigations will provide additional information on growth and environmental requirements and may uncover problems that require attention.

Growth Through Agricultural Progress

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